Cooling Water Chemistry, Corrosion Products and their effect on Accelerator Operation at the Diamond Light Source

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Theme: Cooling Water Quality

Abstract:
Several Synchrotron Facilities have reported on their experience and reliability problems associated with their demineralised water cooling system(s). The problems arising are generally associated with the water chemistry and its interaction with copper cooling components. Various strategies have been adopted to remove or prevent corrosion products from impacting on the reliability of the facilities. The experiences associated with this issue at the Diamond Light Source are presented.

1-Diamond Cooling Water System and General Chemistry

At the Diamond Light Source (DLS) a separate demineralised water circuit is used for cooling the Storage Ring, Booster and Linac. In common with other synchrotrons the quality of the demineralised water used to cool copper and stainless steel components is controlled by a water treatment plant as illustrated in Figure 1

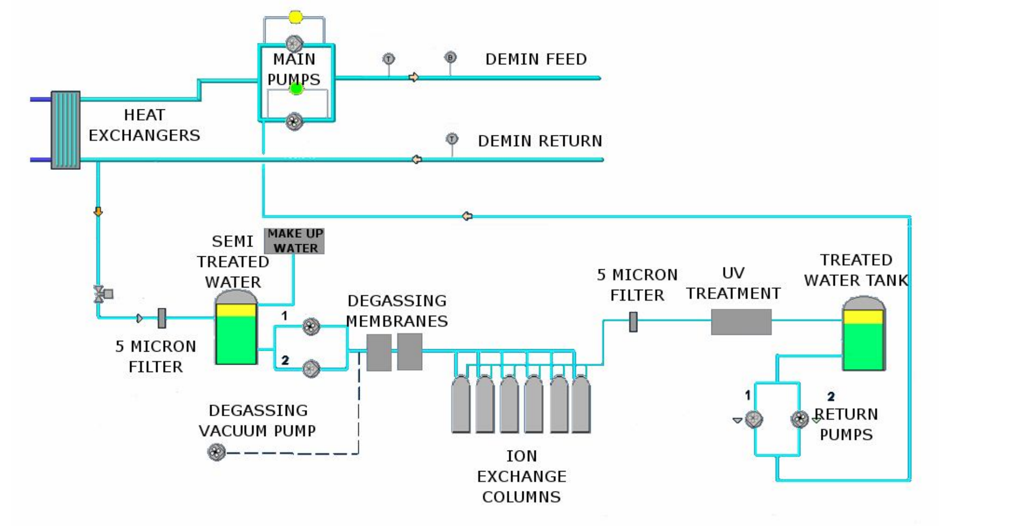

Figure 1: Schematic diagram of the water treatment plant

The total flow capacity of the cooling water for the accelerators is approximately 167 litres/sec and of this 5 litres/sec or 3% of the flow is passed through the water treatment plant.

The water treatment plant consists of two 5micron filters, two holding tanks, degassing membranes, ion exchange columns, and a UV treatment facility for bacteriological control. Nitrogen blankets are used to minimize oxygen and carbon dioxide uptake in the holding tanks.

From previously published information it has been noted that four different regimes of water chemistry are generally considered to minimise the corrosion rate of copper in demineralised water (Refs 1-4). These are illustrated in figure 2 below.

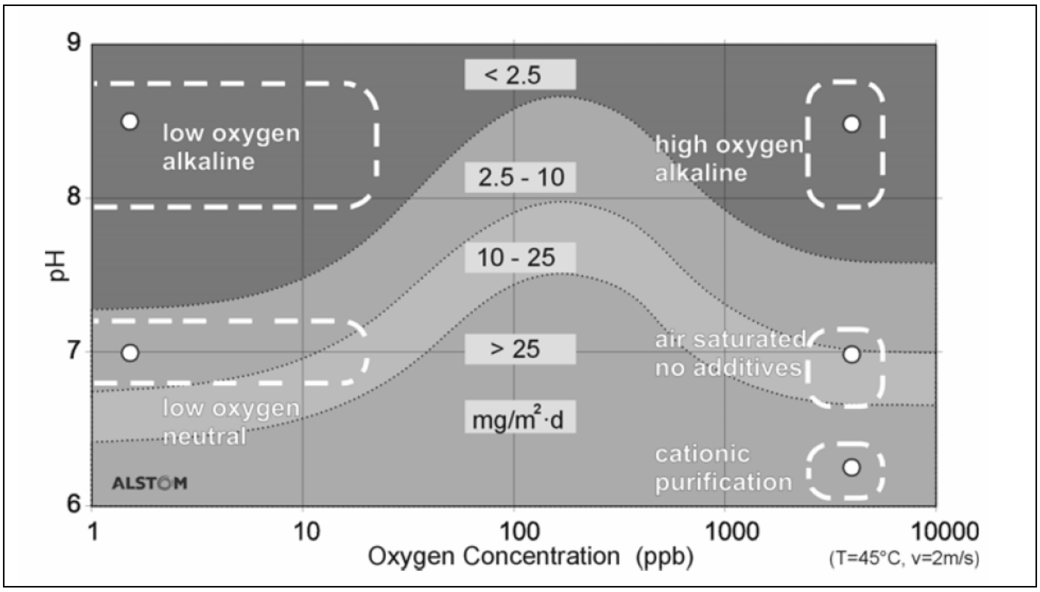

Figure 2: Summary of copper release rates vs. dissolved oxygen and pH highlighting the four operating regimes (ref 2)

At the DLS it was decided from the outset to aim for the 'low oxygen alkaline' regime to minimise oxide formation.

2-Water Chemistry at Diamond

The cooling water circuit under consideration is dedicated to the Storage Ring, Booster and Linac.

The dissolved oxygen and conductivity of the demineralised water are all controlled and monitored; the pH is not actively controlled but its stability is a product of controlling the other quantities. These variables are interdependent and one cannot be controlled in isolation from the others. All these properties vary with temperature but the global variation in temperature of the cooling water is not significant. These three characteristics of water quality have been monitored since the start of the facility operation.

The target pH value is 8 and the average achieved value is 8.1, but there have been short excursions to 8.5 and over 9 on occasions.

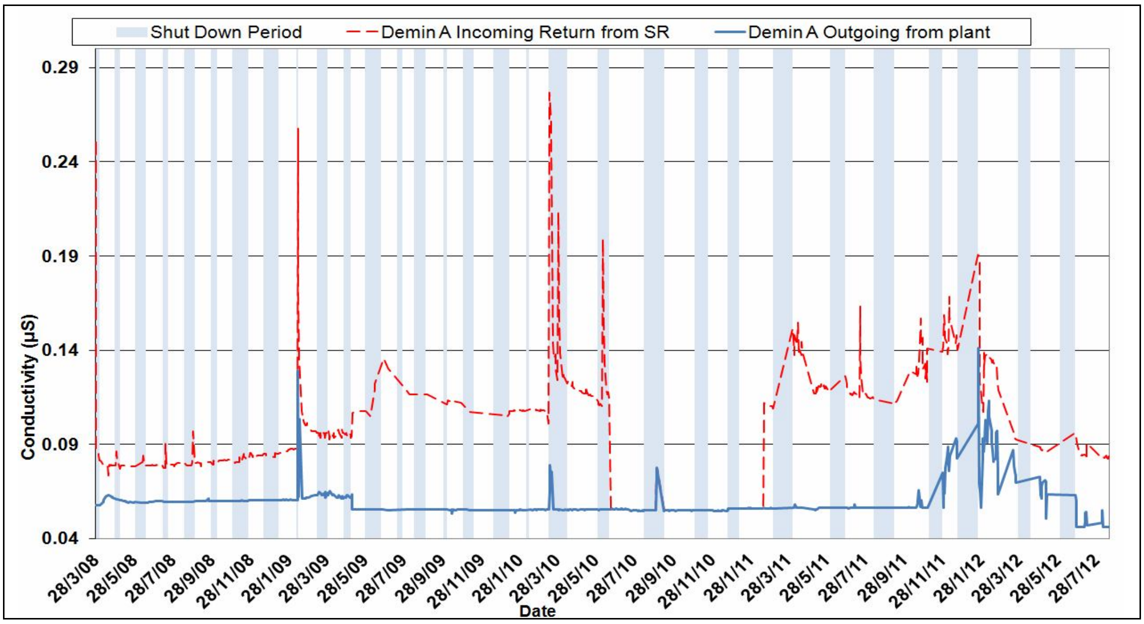

Figure 3: The variation of conductivity against time for the demineralised water circuit. Shutdown periods are shaded vertical bars

The target conductivity delivered by the water treatment plant is 0.1µS, and the lowest value achieved is 0.06µS.

Apart from some isolated excursion the conductivity of the returning water varies between 0.1 and 0.14µS. In 2012 it has improved to below 0.1µS.

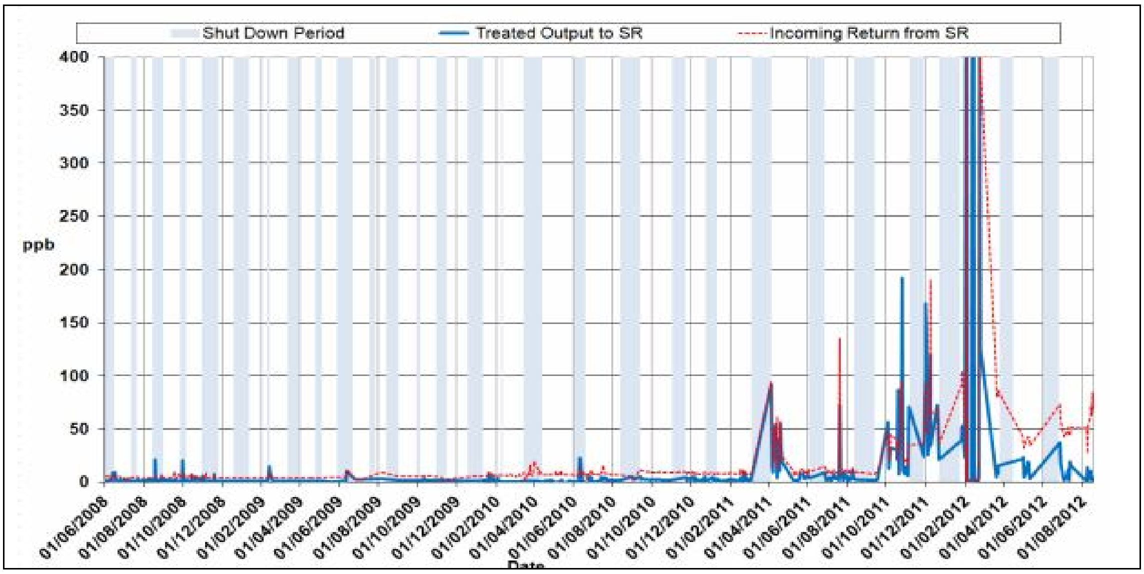

Figure 4: The variation of dissolved oxygen against time for the demineralised water circuit. Shutdown periods are shaded vertical bars

The target value for dissolved oxygen supplied by the water treatment plant is 10ppb, but historically levels have varied greatly. It has been noted in figure 2 that excursions into the 100-500ppb region maximize the corrosion rate and this has occurred on a number of occasions. Other similar facilities have reported that the dissolved oxygen increase is maximized during maintenance periods when water cooled equipment is being installed or modified. The frequency of readings at DLS is insufficient to determine whether the changes occur during shutdowns.

The reason why corrosion rate and hence particle release maximizes in dissolved oxygen excursions is due to a change in the balance between copper I and copper II oxides (Refs 1 and 3) possibly by phase changes between the two oxides affecting their ability to adhere to surfaces . The Pourbaix diagram (ref 5) for copper in an aqueous solution shown in figure 5 shows that at a pH of 8 both oxides can exist.

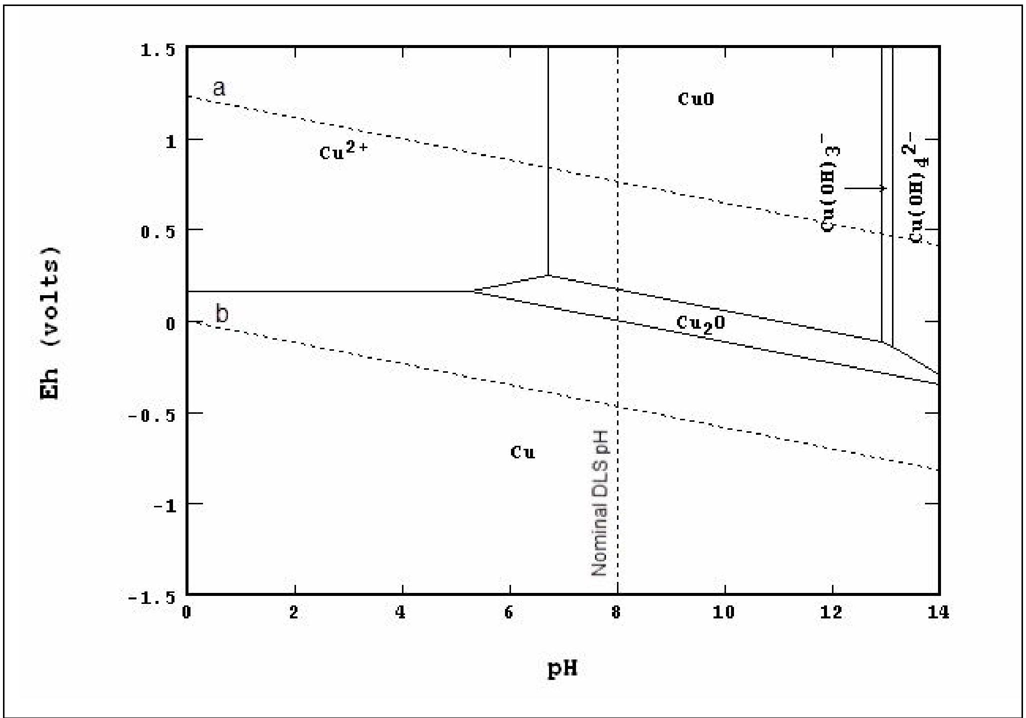

Figure 5: Pourbaix diagram for copper in an aqueous solution at 22°C (using STABCAL courtesy of Dr H H Huang, Montana Tech)

Pourbaix diagrams show which ions and compounds are stable for different electrode potentials with varying pH. The two sloping lines 'a' and' b' in figure 5 represent respectively the fully saturated condition for oxygen and hydrogen. Outside of these potentials oxygen or hydrogen gas will evolve in the water.

At DLS the quadrupole and sextupole magnets operate at +12 to +14V potential with respect to the water pipework, and the dipole magnets from +200V to -200V around the Storage Ring. Reduced conductivity water is used to cool the accelerator magnets specifically to avoid charge transfer which would cause current leakage to earth and electrolysis of the water. As the conductivity of the water increases due to contamination, oxygen gas may be generated at the copper/water junctions and produce oxides. The charge transfer involved would be too small to be measured as an earth current leakage. It has so far not been possible to prove that this phenomenon is occurring.

3-The Problems Associated with Contaminants in the Demineralised Water System

During the first 4 years of operation (2007-2010) the only manifestation of contamination in the demineralised water system was discolouration of the transparent plastic bodies of the variable area (VA) rotameter flow meters.

The VA tubes are located on the return pipework of various storage ring component groups. A cleaning and recording campaign was commenced in order to assess whether this was an early plant life phenomenon and observe whether the rate of discoloration would decrease with time. The rate of discoloration of cleaned tubes has been observed to decrease.

Analysis of the deposit using the Xanes (X-ray Absorption Near Edge Structure) Beamline at DLS proved that the deposit consists entirely of CuO with no Cu_2O present.

In a reduced oxygen environment there should be some Cu_2O present (reference and figure 5, but none has been found in the water so far. Possibly this material has better adherence to the copper surfaces and is not taken up by the water. The reason for the absence of Cu_2O remains unresolved.

Tests have been carried out to determine whether copper oxides are continuing to be generated or whether some equilibrium had been reached. In order to do this some copper coupons were placed in a bypass circuit and left for varying periods of time; the results are shown in figure 6. The progressive build up of black copper II oxide can clearly be seen.

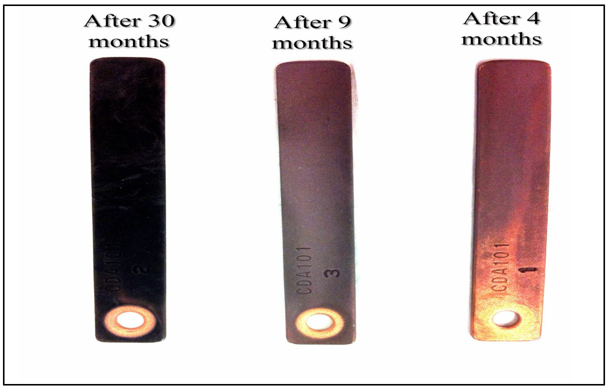

Figure 6: Copper coupons exposed to the demineralised water circuit. Right to left 4months, 9 months and 30 months

Since the start of 2011 a number interruptions to machine operations have occurred as a result of low water flow alarms. The low flows were caused by flow control valves becoming clogged with copper oxide. All of the blocked valves were those required to be nearly fully closed in order to balance the water flow. Some of the energy absorbing components which have narrow and tortuous cooling channels are also becoming clogged requiring interventions and back flushing to clear the accumulated oxide.

As copper oxide particles are accumulating in the cooling water the components most susceptible to clogging are starting to reduce water flow to the point where low flow alarms are causing machine downtime.

4-Solutions to the Problems

There are four routes to preventing the buildup of copper oxide particles from impacting on machine availability.

The first is to start a campaign of replacing the most restricting valves and absorbers with less restricting versions. For valves this is achieved by reducing their body size to more closely match their flow range to the actual flow, or by replacing them with appropriately sized orifice plates.

The second is to introduce more filtration. Investigations show the particle size distribution to be between 1 and 10 microns with a bias towards the smaller sizes. A series of small local filters between 2 and 7 microns have been tested and successfully remove the particles, but due to their small capacity rapidly become blocked. The reason why the 5micron filters in the water treatment plant have never shown any trace of oxide capture remains unexplained. Other similar facilities have installed full system filtration plant (e.g. ref 6).

The third is to dose the water circuit with copper oxide sequestering chemical agents. A number of these have been developed for the power generating industry. Although these chemical mixes will alter the pH balance of the system temporarily.

A fourth consideration which may reduce oxide generation would be to reverse the polarity of the storage ring magnets to turn the cooled copper magnet coils from anodes to cathodes.

5-Conclusions

There has been a steady accumulation of copper oxide in the demineralised cooling water system at DLS which has reached the point where it is affecting machine reliability. Four strategies have been suggested for resolving the problem. The first, component replacement, is well underway. The other three suggestions are under discussion.

References

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